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Platform configurations for local and private 5G networks in complex industrial multi-stakeholder ecosystems

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ABSTRACT

Data and connectivity platforms play a crucial role in the digitalization of different sectors of our society. In complex industrial multi-stakeholder ecosystem contexts connectivity and data platforms are increasingly becoming converged, and private, vertical-specific local 5G networks are emerging. For this context, we depict and analyze alternative configurations for converging connectivity and data platforms and propose appropriate management actions for combining these platforms and achieving legitimacy. We examine a complex industrial multi-stakeholder ecosystem of a port and observe that in the considered case study, the convergence of connectivity and data platforms enhances digitalization and helps to create shared local information between stakeholders. The research identifies a set of regulatory challenges for local 5G networks in complex industrial multi-stakeholder ecosystems where the telecommunication and information technology-related regulations meet with vertical-specific regulations, leading to a complex environment in which to operate. As highly country-specific, these regulations can open new business opportunities or significantly slow down or even prevent a market opening to local private 5G networks for vertical-specific use.

1. Introduction

With the introduction of 5G networks, many industrial companies are seeing new opportunities for digitalization (Palattella et al., 2016; Pujol, Elayoubi, Markendahl, & Salahdin, 2016) and industry 4.0 transformation (Brettel, Friederichsen, Keller, & Rosenberg, 2014). Industry 4.0 has already brought about various *data platforms*—such as cloud services—and related services to the industrial context. 5G and its promises of improvements in supporting critical and massive machine-to-machine communications may mean enormous efficiency and quality enhancements. In vertical industrial contexts, the role of local and private 5G networks has emerged as an increasingly important topic (Matinmikko, Latva-aho, Ahokangas, & Seppänen, 2018; Matinmikko, Latva-Aho, Ahokangas, Yrjölä, & Koivumäki, 2017). For these kinds of highly localized and heterogeneous environments where security, privacy, and vertical- and user-specific requirements play an important role, private local 5G networks (Lemstra, 2018; Matinmikko et al., 2017) can be a solution. As a disruptive and emerging innovation, private local 5G networks may share several "industry legitimacy" or "industry acceptance" related challenges (Kwak & Yoon, 2020; Marano, Tallmann & Teegen, 2020) that need to be considered.

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The 5G network itself has been understood as a *connectivity platform* (Ahokangas et al., 2019), and it can be extended toward data platforms, connecting intelligence and services. However, combining or converging various data platforms and connectivity platforms in vertical industrial contexts is a challenging task that comprises drivers, opportunities, barriers, and limitations related to business, technology, and regulation. Extant research has employed different classifications and logics for platforms-based ecosystems in vertical industrial contexts such as product- or process-related methods (e.g., Weking, Stocker, Kowalkiewicz, Bohm, & Krcmar, 2020) and approaches based on business models (e.g., Iivari, Ahokangas, Matinmikko-Blue, & Yrjola, 2021) or roles (e.g., Gawer, 2009). When discussing the converge of connectivity and data platforms, the platform configuration emerges as a central issue. Extant literature in the field covers the data platform configuration perspective (Yrjola, Ahokangas & Matinmikko-Blue, 2019) and the connectivity platform s technical value configuration perspective (Ballon, Walravens, Spedalieri, & Venezia, 2008; Casey, Smura, & Sorri, 2010). These perspectives can fundamentally be considered based on resource configurations (Amit & Han, 2017). However, as a result of the industry 4.0 development, industrial verticals are increasingly discussed as *platform ecosystems* where the wireless network is becoming integrated with other ICT infrastructures and services meaning that connectivity and data (or cloud) platforms are converging and giving rise to a 5G-enabled platform ecosystem (Pujol, Elayoubi, Markendahl, & Salahaldin, 2016). For example, factories and industrial areas such as harbors or mines are examples of industrial multi-stakeholder ecosystems that could rely on common platforms. Platforms, in general, have been categorized as a) company-internal platforms where the platform serves only internal purposes, b) supplier-network platforms that integrate the data of value chain partners to serve information flow purposes, or c) ecosystem platforms that may serve various purposes of also changing partners (Gawer & Cusumano, 2014). The first two platform types represent traditional vertical industrial and relatively closed platform constellations (c.f., Cusumano, 2004) with closed wireless networks.

Currently, the connectivity and data platforms in industrial settings are often fragmented, although both connectivity and data platform providers aim at providing centralized and combined services. In practice, this means the emergence of various kinds of hybrid forms and actor roles in these platform constellations forms and roles that hamper these platforms legitimacy and scalability. Extant research lacks a suitable approach or framework that could characterize, explain, and manage connectivity and data platforms convergence in vertical industrial contexts. Also, the emergence of 5G-enabled platform ecosystems gives rise to several regulatory challenges. These challenges come from telecommunications regulations, information technology regulations, and the vertical-specific regulations of different industries. The country-specificity of these regulations increases this complexity as they might have completely different starting points.

Overall, the above discussion on the connectivity and data platform convergence in vertical industrial contexts under relevant regulations directs attention to industry legitimacy challenges. In general terms, legitimacy may be seen to mean that the converged connectivity and data platform constellations are considered appropriate for and accepted by the industry s relevant stakeholders (Kwak & Yoon, 2020; Suchman, 1995). This research aims to explore the challenges of converging connectivity and data platforms in vertical industrial contexts. As a specific future-oriented case, this research focuses on a port that is building a private 5G-enabled platform ecosystem to benefit from digitalization and to service its stakeholders. In general, ports represent an example of multi-stakeholder industrial ecosystems in which the stakeholders may have conflicting interests (De Langen, 2006; Frosch & Gallopoulos, 1989; Haraldson et al., 2020, pp. 47 63; Senyo, Effah, & Osabutey, 2021) and where digitalization may bring substantial benefits. As a multi-stakeholder ecosystem, this kind of setting is specifically suitable for researching the convergence of connectivity and data platforms as it represents a plethora of activities and goals that are partly shared, partly conflicting, and which are conducted under different regulatory requirements, thus being able to provide rich empirical data. By using the port as a case, this research seeks to answer the following questions:

1. What kind of connectivity and data platform configurations may emerge in the digitalized industrial multi-stakeholder platform ecosystems of private 5G networks?
2. What management actions could characterize the 5G connectivity and data platform configurations in industrial multi-stakeholder platform ecosystems of private 5G networks?
3. What regulatory challenges arise in the industrial multi-stakeholder platform ecosystems of private 5G networks?

The expected outcomes of the paper are two-fold. First, we contribute by showing how 5G-enabled platform ecosystems may emerge and configure in future complex industrial multi-stakeholder ecosystems, especially from connectivity and data platform perspectives. Second, we propose management actions for creating legitimate converged data and connectivity platform configurations and identify related regulatory challenges. To this aim, this research applies a case-based, futures-oriented, and exploratory action learning methodology. The data for the analysis is based on two workshops held in June 2019 and August 2019 to describe, explore, and analyze the port ecosystem in the first place. The workshops data was complemented with two interview rounds with the port management in April and May 2020. The interview rounds deepened the data generated in the workshops and allowed the researchers to analyze the port s digitalization from the connectivity and data platform perspectives.

The paper is structured as follows. After the introduction, the related work is presented in three parts. First, as the technological starting point, 5G networks are outlined as connectivity and data platforms (Chapter 2.1). Second, multi-stakeholder platform ecosystems and their challenges are discussed (Chapter 2.1) and the related regulatory developments outlined (Chapter 2.3). Next, the research methodology (Chapter 3.1) and context (Chapter 3.2) are presented. Next, the research findings are presented in two main parts: first by outlining the port ecosystem (Chapter 4.1) and second by building on the port case, we present and analyze (Chapter 4.2) alternative platform configurations as well as propose appropriate and legitimate management actions (Chapter 5) for combining connectivity and data platforms. To conclude, Chapter 6 identifies regulatory challenges, and Chapter 7 presents the conclusions.

2. Related work

This chapter provides a thematic background to analyze the challenges of private and local 5G networks in complex industrial multi-stakeholder platform ecosystems. In Chapter 2.1, the private 5G networks are outlined as connectivity and data platforms from a technical perspective as a starting point for understanding the challenges facing 5G-enabled multi-stakeholder platform ecosystems. The framing for this is presented in Chapter 2.2 through platform ecosystems. Finally, Chapter 2.3 highlights recent regulatory discussions in this context.

2.1. Technological starting points for private and local 5G networks

5G technologies are expected to transform future wireless networks in five areas: 1) densification and extreme capacity through millimeter-wave small cells in the access network (Schneir et al., 2019); 2) localization via the distribution of radio and core functions, content, and services on edge clouds to pool gains, and to achieve low latency, high reliability, security, and privacy; 3) decomposition of network functions utilizing interconnected distributed datacenters and cloud infrastructure to increase flexibility and scalability; 4) softwarization of the network with advances in analytics and machine learning to enable a high level of automatization in management and orchestration, and; 5) network virtualization, particularly network slicing, utilizing the above capabilities to enable a variety of new as-a-service business models (3GPP TS 38.300; 3GPP TS 29.500; Cave, 2018; Morgado, Huq, Mumtaz, & Rodriquez, 2018).

5G technology is standardized by the 3rd Generation Partnership Project (3GPP) in standards releases. The first 5G Release 15 standards completed in June 2019 specified a standalone (SA) architecture that supports new 5G radio access and the new 5G core network focusing on enhanced Mobile Broadband (eMBB) use cases. 3GPP has considered the requirements of vertical domains from Release 16 onwards, introducing capabilities for industrial Ultra-Reliable Low Latency Communication (URLLC) use cases in June 2020 and targeting Release 17 (planned for December 2021) to focus on high numbers of IoT devices, also known as massive Machine-Type Communication (mMTC). Furthermore, a 5G Non-Public Network (NPN) architecture for private networks was specified in release 16 (3GPP TS 23.501). NPNs are divided into two main types: Standalone NPN (SNPN) is a fully isolated complete 5G system that does not interact with any mobile network operator s (MNO) 5G network, while a Public Network integrated Non-Public Network (PNI-NPN) relies at least partly on MNO s infrastructure for 5G system functions.

A critical aspect of the new local and private industrial 5G network is creating customized network slices, where instances of virtual network resources and applications can be delivered to a new breed of services tailored to specific customer needs with service-level agreed performance on demand. Application and service providers will be able to use a sub-set of the network capabilities in a flexible, configurable, and programmable manner, depending on their service preferences. Furthermore, a software-based network architecture enables efficient sharing of common network infrastructure by different tenants. Abstracting the network slice functionality by utilizing open interfaces and third-party service provisioning enables a service-dominant model for the connectivity and underlying network resources, e.g., computing, data, and intelligence (Frias & Martínez, 2018). The edge cloud provided by the connectivity provider or cloud service provider could become an enabler of platform convergence and the control point of local connectivity, data, applications, and services. A hybrid data platform model can improve coordination between stakeholders by sharing data in a centrally coordinated manner. The cloud embedded in the edge of the network provides the optimized performance and economics for both the virtualized network functions and any other performance-critical enterprise or vertical service. It represents the source and destination of much of the demand combined with data and context analytic-enabled optimization capabilities. The edge cloud use cases considered in 5G include, e.g., the cloud radio access network (Open RAN, Virtual RAN), edge security, network, and service automation enhancing the network itself, industrial automation, massive-scale IoT, and augmented intelligence with augmented/virtual reality (Mell & Grance, 2011). Open interfaces to network data enable operators to combine local radio access data with various data lakes, such as 3D building maps and industrial data from different sources, to automatically manage and orchestrate their networks, resources, and services and improve their customers experience. Moreover, this approach can utilize the digital twin concept (Gelernter, 1993) and leverage artificial intelligence/machine learning algorithms to simulate network behavior ‘in the digital world, based on the 5G use cases, each with capacity, coverage, and performance needs of their own.

2.2. Framing platform ecosystem challenges for private and local 5G networks

Due to the industry 4.0 development, industrial verticals are increasingly turning to platform ecosystems where the wireless network becomes integrated with other ICT infrastructures and services. This integration means that connectivity and data platforms converge and give rise to a 5G-enabled platform ecosystem where diverse connectivity and data services can be packetized in novel combinations and by new ecosystem stakeholders. From the ecosystem perspective, the converging connectivity and data platform ecosystem can be seen as a digital platform-operated ecosystem (Gawer & Cusumano, 2014; Phillips & Ritala, 2019), or a technology ecosystem (Thomas & Autio, 2019), and can therefore be considered a partial digital representation of a physical business ecosystem (Nachira, Dini, & Nicolai, 2007) as a digital twin of reality (Lanzolla, Pesce, & Tucci, 2020).

Platforms and ecosystems come in a variety of forms and have varied definitions. McIntyre and Srinivasan (2016, p. 143) define platforms as interfaces often embodied in products, services, or technologies that can serve or mediate transactions between two or more sides. Ecosystems, specifically industrial ecosystems, are related to product/service systems (Tsujimoto, Kajikawa, Tomita, & Matsumoto, 2018) and consist of a set of actors with varying degrees of multilateral, non-generic complementarities that are not fully hierarchically controlled (Jacobides, Cennamo, & Gawer, 2018, p. 2264). The complementarities may be generic or stem from specialization, i.e., they may be related to a specific purpose or co-specialization in collaboration with partners (Skold, Freij, &

Frishammar, 2020). Generally, platforms have been considered to grow an ecosystem of complementors around them (Gawer, 2014), making these two concepts (platforms and ecosystems) intertwined. Earlier research divides platforms into three categories: 1) a company and its internal units (internal platforms, either company or product platforms); 2) the network of a company and its suppliers (supply chain platforms); and 3) an ecosystem keystone actor and its supplementary actors in a technology or business ecosystem (ecosystem platform) (Gawer, 2014). As stated above, a platform s complementors are not, however, necessarily hierarchically controllable (Jacobides et al., 2018). Especially internal company or product platforms can efficiently form a basis for a stream of derivative products, upon which the whole ecosystem can develop their complementary products, technologies, and services (Gawer & Cusumano, 2014).

The combined platform and ecosystem perspective point to look at the degree of openness in the multi-stakeholder platform ecosystems. Related to openness, complementarity which can be related to production, customers, asset prices, inputs, technologies, or innovation (Teece, 2018) can be seen as the basis for converging or combining platforms. Openness at the edge(s) or of the platform s core, or even open-source (Casadesus-Masanell & Llanes, 2011) may be selected as a strategy for building converged multi-stakeholder ecosystems. In a port context, Iivari et al. (2021) highlight the importance of data access and ownership and algorithms in managing platform ecosystems. They also discuss the role of governance, competition and cooperation, and economies of scale and scope in this regard. Consequently, attention needs to be paid to the technical platform modularity and architecture and service modularity and architecture (Yrjola, Ahokangas, & Matinmikko-Blue, 2019).

The business environment for deploying local and private 5G networks with novel stakeholders, such as local operators, facility users, and facility owners (Matinmikko et al., 2017), will disrupt the mobile communication market. However, in the same way as the individual actors in this emerging new market, the whole concept of local private 5G networks calls for legitimation. Legitimacy in the industrial context means the consonance of an industry with its institutional environment (Kwak & Yoon, 2020), and it should be differentiated from legitimation given by a regulatory body. Legitimacy can be understood to be the ability to select the right thing to do (Palazzo & Scherer, 2006) in the ecosystem as it pertains to a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions (Suchman, 1995). For new stakeholders such as local operators, this may prove to be controversial. Innovations (Ansari, Garud, & Kumaraswamy, 2016) and disruptive and emerging technologies such as 5G are often associated with lower legitimacy and higher uncertainty (Rotolo, Hicks, & Martin, 2015; Amit, Snihur, & Zott, in press), although legitimation can be seen as a precondition for successful value creation and capture concerning a technology (Biloslavo, Bagnoli, Massaro, & Cosentino, 2020). Disruptive innovations have earlier been found to cause regulatory, incumbent, and social pushbacks (Marano, Tallman, and Teegen (2020).

Thus, for achieving legitimacy in the industrial context, platform ecosystem stakeholders may adopt passive or active legitimation strategies (management). Passive acceptance strategies build on the familiarity of existing institutions or the absence of alternatives. In contrast, active evaluation of legitimation may occur via a pragmatic route, meaning that the innovation satisfies ecosystem stakeholders self-interests and does not influence others negatively. The pragmatic route can either mean the sociopolitical route in which the innovation complies with established social rules, regulations, and norms or the industry legitimation route in which the innovation fits with the industry s institutionalized practices. Moral legitimacy for the actions may be granted by normative evaluations, e.g., by the regulative bodies. Finally, cognitive legitimacy for actions may be achieved if the industry is taken for granted by the stakeholders (Kwak & Yoon, 2020).

2.3. Regulatory developments influencing private and local 5G networks

In addition to achieving legitimacy for the new concept of local and private 5G networks in the industrial context discussed in Chapter 2.2, their deployment in complex industrial multi-stakeholder platform ecosystems is directly influenced by regulatory developments, which are reviewed next. These regulatory developments also have direct consequences on the legitimacy of the activities of the platform ecosystem participants. The electronic communications market is highly regulated, with varying degrees at national, regional, and international levels. While there are wide variations in the national regulatory approaches, there are also different levels of harmonization, such as in the European Union (EU) member countries through the European Electronic Communications Code (EECC). In addition to the telecommunication-specific regulations, the digitalization of various industries calls for proper digital industrial policies that take into account the fundamental changes that the inclusion of digital technologies will bring to the industries (Gruber, 2019).

Lemstra (2018) presents two contrasting scenarios for 5G in Europe and the related regulatory debate. In the first evolution scenario, dominance by MNOs continues, and the scenario is likely to evolve under the current EECC. The second revolutionary scenario allows particular industry vertical sectors to be served with tailored feature sets provided by new virtual MNOs and will require additional policy and regulatory measures. In providing a tailored service experience, an extensive policy debate exists around the network neutrality principle in which all traffic through the Internet should be treated equally, which has a major influence on 5G services (see Frias & Perez Martínez 2018).

Recent studies on regulatory developments and legitimacy for local 5G networks (Matinmikko et al., 2018) have identified a number of key regulatory elements to be considered, including access regulation, pricing regulation, competition regulation, privacy and data protection, and the authorization of networks and services. Especially relevant for local operators are access regulations concerning the obligation for interconnection and interoperability, requiring that operators offer connectivity to virtual operators and other operators that lack part of the network. Pricing regulations that aim to prevent wholesale and transfer prices from distorting competition will also influence local networks operations similarly to competition regulations that aim to ensure that competition in the market does not restrict economic welfare and innovation. Privacy and data protection that aims to ensure users rights to data and the processing of their data, and privacy to protect confidentiality and security of services, such as the GDPR in Europe, will play an important role in the local networks where various data will be used. Finally, the authorization of networks and services defining how the rights to use radio frequencies are granted is critical for establishing local private 5G networks.

For the specifics of the spectrum regulatory framework for local 5G networks, the key regulatory elements presented in (Manosha, Matinmikko-Blue, & Latva-aho, 2017, pp. 1 8) consist of the purpose of use, eligible licensee, license awarding procedure, technical conditions, license area, obligations, transferability of rights, and the license duration. An overview of recent 5G spectrum awards decisions in (Matinmikko-Blue et al., 2019) shows how different countries have taken diverging approaches in assigning the 3.5 GHz band to operators, including country-wide auctioning of the spectrum to existing MNOs and local licenses for facility owners. Specific spectrum options for local 5G networks were analyzed in more detail in (Vuojala et al., 2019), including unlicensed access, secondary licensing, spectrum trading/leasing, and virtual network or local licensing.

3. Research methodology and context

3.1. Research approach

The multi-stakeholder platform ecosystem perspective adopted in this paper for analyzing emerging local 5G networks in the vertical industrial context raises questions concerning the platform ecosystem configuration, its contents, and stakeholders role. To analyze the topic and answer the research questions, a case-based exploratory and futures-oriented action learning approach (Inayatullah, 2006, 2007) was selected. Anticipatory action learning is a democratic process that comprises inquiry, anticipation, learning with action, assessment, and decision-making. The approach aims to make multiple levels of understanding merge openly and progressively during the process and underline experimenting, reflecting, and learning (Reason & Bradbury, 2008). The method provides rich data in case-based situations such as workshops in which the stakeholders are confronted with a need to act, as in the case of building private 5G networks. Action learning accounts for the context in a holistic manner for finding appropriate action (Susman & Evered, 1978), thereby achieving generality related to expected implications for the future. In assessing the research outcomes, we followed Reason and Bradbury (2008) and paid specific attention to the quality of participation, practicality of outcomes, diversity in the ways of knowing in the context, reflection, and development of systematic change.

This research builds on the Finnish 5G-Viima research project on 5G in industrial environments and applications that brings together 27 organizations presenting industry, academia, and the public sector. The project s specific focus is on private 5G network ecosystems in factory and port contexts, and the consortium includes stakeholders from these ecosystems. The focus case in this paper is the port ecosystem. Port represents a complex, multi-stakeholder industrial platform ecosystem of both closed, partly open, and fully open functionalities, and it serves various goals and activities of the stakeholders subject to various regulations.

The research data was collected within the 5G-Viima project consortium in two phases in 2019 and 2020. In the first phase, two workshops were held in June 2019 and August 2019, where representatives from all 27 consortium organizations were invited. The workshops were organized to describe, explore, and analyze the port ecosystem, its digitalization via the development of a digital platform from connectivity and data perspectives and the potential antecedents and outcomes of the digitalization of the port ecosystem for the future. As a part of the 5G-Viima project, 24 people from 13 organizations representing various port ecosystem stakeholders attended the first workshop, and 30 people from 18 organizations attended the second workshop. The workshop participants represented the port itself, the companies working within port boundaries, connectivity and data platform providers and users, the regulators influencing port activities, municipal authorities, and the researchers, some of whom also facilitated the workshops. These stakeholders were considered to have a key role in the digitalization of the port. The authors of the paper representing academia created the generic framework, set the workshops agenda, and facilitated the discussion and data collection. Other researchers also attended the workshops. The data was collected in facilitated group discussions in the form of text written on PowerPoint templates and notes collected by the researchers during the workshops. The first workshop s focus was to gain a comprehensive understanding of the general port ecosystem consisting of its key stakeholders and their key activities, interactions, and constraints. The second workshop was organized to revisit the port ecosystem description and analyze the port s digitalization from the connectivity and data platform perspectives with a focus on the key stakeholders and activities for digitalization.

The second phase of data collection was organized in April and May 2020 by interviewing two key representatives of the port management (the CEO and Head of digitalization) to complement and deepen the workshop data. For the interviews, the researchers created a list of themes based on the outcomes of the workshops. Also, the respondents freely commented on the workshop outcomes. The interviews were recorded and transcribed for further analysis. The research outcomes presented in Chapters 4 and 5 were based on an action research cycle (Dickens & Watkins, 1999). In the action research cycle, foreknowledge and emergent theory in the research field influences data generation and reflection, leading to theory development and influencing how the outcomes are presented for the stakeholders for review, assessment, and further discussion.

3.2. Case of port as an example of a complex industrial multi-stakeholder ecosystem

The case study selected for closer analysis was the Port of Oulu, a complex industrial multi-stakeholder ecosystem located in the north of Finland, participating in the 5G-Viima project. Generally, the port serves as a transport hub through which mainly local industries transport goods. An additional analysis of the port of Oulu can be found in Iivari et al. (2021) and Golzarjannat, Ahokangas, Matinmikko-Blue, and Yrjola (2021). The port is a multi-stakeholder environment with a variety of roles and goals. For its operations and to serve its customers, the port has started to build integrated connectivity and data platforms in which the 5G network plays a

Table 1
Key stakeholders interactions in the port ecosystem.

Stakeholder	Key Activities	Business relation to port	Relation to platforms	Challenges
Cargo owner	To get its goods delivered. Ownership and liabilities for cargo may change during transportation.	Uses port services via transportation/logistics companies	Information and tracking of cargo.	Low volumes, lack of system integrations and transparency.
Logistics/transport companies	Efficient transportation of cargo to/from the port, loading and unloading.	Represents cargo owners and has direct relationship to the port.	Own tracking system. Need data for situational awareness.	Limited visibility of the logistic chain and changes in other stakeholders operations/schedules.
Stevedores	Loading and unloading ships/trucks/trains by using their machinery and infrastructure.	Direct contract with the port.	Own platforms.	Competition between other ports and other port operators, labor unions, local available infrastructure.
Authorities	Governance through rules/regulations/laws, e.g., on environmental topics, security, and safety.	Governing port operations.	Open data sources such as ice data, vessel call data, weather data, railway data, sea conditions, traffic congestion. Own platforms for internal use.	Data sharing between authorities, multi-operator environment, local interpretations of regulation.
Security and safety providers	To ensure security and safety in the port.	Contracted by the port.	Own platforms. Situational awareness important.	Several different actors, cyberattacks. Not possible to control activities or practices, lack of information exchange in multi-actor environment.
Physical port infrastructure	Lighting, piers, safety equipment, sea fairway signs, terminals, warehouses, and other facilities, roads, rail lines, construction.container fields, gates, port pool, bulk liquid pipelines.	(Mainly) owned by the port.	As the main port asset, providing data (e.g. IoT) to the platform.	Environmental protection and regulation, natural conditions. Long life cycles - combining assets over decades, technology expires, massive and costly infrastructure construction built to last decades.
Data and computing platform providers	Storing of data.	The port buys platform services.	To provide platforms to stakeholders.	Lack of substance, invalid data.
Connectivity platform providers	To offer high-quality wireless and wireline infrastructure.	The port buys services from connectivity providers.	Data collected via networks, network data.	MNO s interest in building local capacity; not serving large public consumer groups, yet with requirements for instant revenues. Private network solutions; maturity and quality issues in both technology and new service processes
Digital services providers	To provide digital services for sensors and analytics, video analytics, positioning, edge analytics, etc.	The port buys digital services.	Sensor data and analytics results, visualizations (drones).	Lack of substance.

central role. While the actual physical port operations take place within a fenced area, the transport chains span beyond the port area. Digitalization is increasingly impacting the port operations from two sources: the different stakeholders' digitalization activities inside their own companies and collaborative actions within the port.

The port itself is the central stakeholder in the example port ecosystem, around which the port operations are orchestrated. The key activity of the port is to ensure efficient and smooth port operations for the stakeholders. Through digitalization, the port can enhance the port stakeholders' operations by providing situational awareness to its stakeholders. Table 1 presents an analysis of the key stakeholders' interactions highlighting the key stakeholders' activities, relation to the central stakeholder (the port), relation to digitalization platforms, and related challenges and expectations. The table combines the two workshops' results by going through each stakeholder's key activities, partners, needs, constraints, benefits, and barriers. Table 1 was compiled from profile descriptions of the key port stakeholders regarding digitalization collected in the first workshop, where smaller groups created the stakeholder descriptions for selected sets of stakeholders. The profiles included a) the key activities, goals, resources, competencies, and contributions; b) partners, customers, and competitors; c) key expectations, needs, benefits, challenges, and pains; and d) key barriers, constraints, and objections.

The key issue arising from the workshop data analysis and interviews was the need for situational awareness that could be achieved via a platform. This could form the basis for a digital twin of the port as each stakeholder works independently to fulfill their responsibilities and goals with their specific competencies and are at the same time dependent on the other stakeholders in different workflows. This creates an interdependent set of actors that require situational awareness of each other's activities in the port area. To deal with the complexities arising from this set of activities, connectivity and data platforms can provide access to information and relevant content to create situational awareness based on the individual actors' data collected for that purpose. It is also evident that the stakeholders' activities span the ecosystem's boundaries. Many stakeholders have activities inside and outside the ecosystem's boundaries, creating a "verticals-in-verticals" situation inside the ecosystem, also requiring "across-verticals" collaboration.

4. Developed data and connectivity platform configurations

Next, we present alternative data and connectivity platform configurations to manage emerging private and local 5G networks in industrial settings. The empirical data of the port case was analyzed against the thematic background presented in Chapter 2. Three alternative platform configurations were created for both connectivity and data platforms: fragmented, centralized, and hybrid configurations. In the fragmented platform configuration, each of the stakeholders would develop a separated, stakeholder-specific connectivity and data platform, which would be developed or acquired for their needs. Shared connectivity and data platform would be created to build common and shared services in the centralized platform configuration, although each stakeholder would maintain systems to manage their internal data and services. The in-between hybrid platform configuration shared elements from both the centralized and fragmented configurations. Next, we discuss these three basic configurations in detail.

4.1. Alternative platform configurations

The fragmented platform configuration reflects the situation where each of the ecosystem stakeholders has developed or acquired data and connectivity platforms that only serve their own internal needs. Varying performance and functionality requirements are set forth and achieved by the stakeholders with varying costs and benefits. No dominant player exists within the ecosystem—although the central player, the port authority, acts as the common landlord for the other stakeholders. Also, minimal coordination occurs between the stakeholders as they seek maximum freedom. This configuration resembles the company-internal ecosystem approach in that although the key stakeholder groups operate within the area boundaries, there is minimal, and for the most part, one-on-one communications, and interaction. This interaction exists to serve all stakeholders' common customers, although not necessarily the stakeholders present within the port area. Each of the stakeholders has its own siloed connectivity platforms that may consist of WLAN and mobile networks. These are the necessary data platforms and services they need to perform their activities. No shared data-based

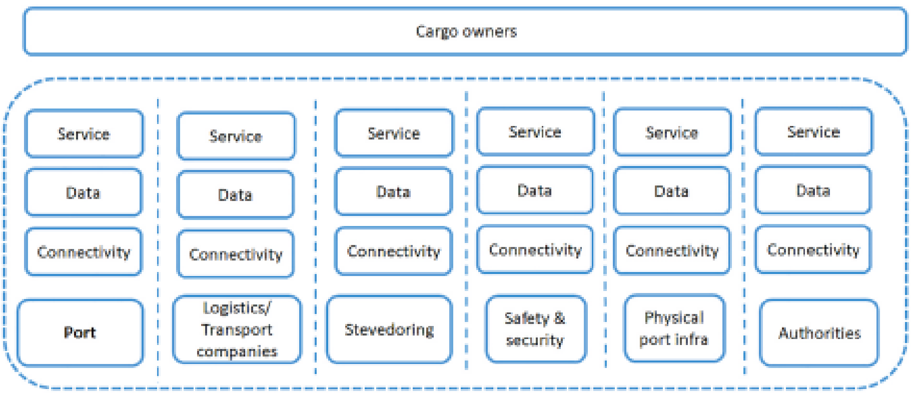

Fig. 1. The fragmented platform configuration.

services exist in the ecosystem, although centralized clouds may be used remotely. As fragmented internal solutions dominate, the stakeholders enjoy only a weak situational awareness of the area of operations. This is explained but also made challenging because most of the port's stakeholders also operate outside the port area in other locations. Thus, the stakeholders' attention should be on 1) the value-add created and enjoyed by the stakeholders and 2) the ease of data collection in the platform. Fig. 1 depicts the fragmented platform configuration for one stakeholder, the cargo owner.

The centralized data and connectivity platform configuration is depicted in Fig. 2. The centralized configuration is the functional opposite to the fragmented configuration discussed above and has a dominant central coordinating player for the data platform and the connectivity platform, which can be the same player. Although it is natural to consider the central player to act as the coordinating player for the connectivity and data platform and related services, to provide tailored and guaranteed high-quality performance and functionality for the other ecosystem stakeholders, in reality, the central player will not necessarily have the capabilities necessary and needs to buy them as services from the outside. As a result, better cost benefits of platform services and better situational awareness of the industrial activities in the area between other ecosystem stakeholders can be achieved. This configuration resembles a value-chain ecosystem approach, where each player serves the common customer as if separately, but as a part of an organized value chain where shared platforms and services play a central role. Although the ecosystem stakeholders also have their internal data, services, needs, and solutions, the shared platforms fully orchestrated by the central coordinating player enable the stakeholders to enjoy a good situational awareness of ongoing operations.

The hybrid platform configuration presented in Fig. 3 shares characteristics of both the centralized and fragmented platform configurations. Although there is a central player, that player does not assume a dominant role in the ecosystem but builds a connectivity and data platform with selected services to serve the port ecosystem's shared goals. Each of the other ecosystem stakeholders still focuses on data that plays a central role in their operations, whereas connectivity and services based on other stakeholders' data may be acquired from the port's platforms or other providers. Although this configuration's cost/benefit ratio may not be the best, it nevertheless enables the provisioning of data services for all stakeholders. At the same time, it also helps to achieve a good situational awareness of relevant activities for all ecosystem stakeholders.

4.2. Analysis of developed platform configurations

Next, we analyze and present alternative connectivity and data platform combinations. Table 2 presents a more detailed description of the resulting nine alternative connectivity and data platform configurations by using the centralized-hybrid-fragmented categorization as a basis. The categorization emerged based on analyzing platform and ecosystem levels separately (Iivari et al., 2021) for their configuration, reflecting the thematic background presented in Chapter 2, and examining the way connectivity and data platforms were offered in practice to the port's stakeholders. Note that Table 2 indicates the fundamental separation of business roles for the data platform, connectivity platform, and potentially for each service running on top of these. However, in practice, a company, or an actor, may adopt more than one business role. For instance, a data platform provider (e.g., a cloud service provider) may provide both data and connectivity as a service via a marketplace, or a connectivity platform provider (e.g., private network operator) may also operate a data platform on its connectivity platform. However, a healthy service ecosystem assumes that multiple actors can operate multiple services on top of a single platform or that services operating on different data platforms can interconnect using agreed standards.

In centralized connectivity, one dominant player, either an MNO or a private network operator, provides the connectivity platform and connectivity services. However, if analyzed across different data platform configurations, we may observe quite large differences regarding the role, availability, and access to data and services. If data platforms are centralized, all services may become provided as a service by one dominant data player, cloud service provider, or any data-intensive stakeholder, whereas if the data platform is of a

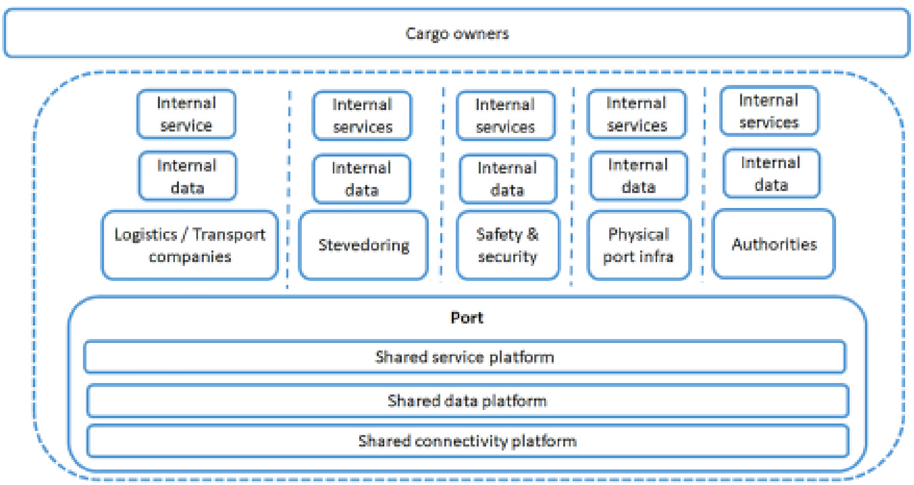

Fig. 2. The centralized platform configuration.

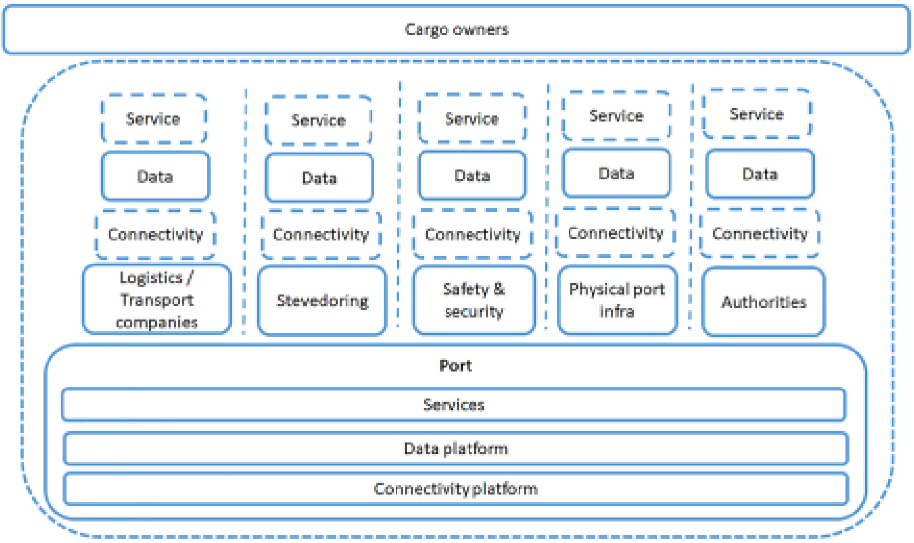

Fig. 3. The hybrid platform configuration.

hybrid type, only platform-specific data may be provided as a service. This may be due to the increased fragmentation of the platforms. If the data platforms remain completely fragmented and siloed, self-service and one-on-one data sharing are assumed to prevail. In hybrid connectivity, several parallel connectivity providers, either MNOs, neutral hosts, or private network operators, may exist. The connectivity platform's hybridity and services may be reflected as the wider variation in the data platform. This may be related to the fact that connectivity and data services may be combined differently by different providers. Regarding fragmented connectivity platforms and services, each stakeholder assumes responsibility for just their own needs and builds the connectivity either themselves or buys it from a mobile network operator. In contrast, data platforms and services may be assumed to follow the same logic as centralized connectivity.

Based on this analysis, we argue that an optimally hybrid data platform with an optimally centralized connectivity platform appears to be a likely legitimate configuration for converged connectivity and data platforms. First, as the port stakeholders may have different activities and goals, their data content and platform requirement may vary considerably, thus leading to a situation where a fully centralized data platform would be unrealistic at the platform ecosystem level. Also, a completely fragmented data platform could be inefficient for enabling the development of the desired digital twin. Second, regarding the connectivity platform, the number of possible service providers for the port stakeholders is typically much lower, leading to a situation where a centralized connectivity platform provided by a trusted partner could turn out to be efficient. When it comes to the connectivity and data platforms' specifics, the actor vs. business role for these two platforms can be an important distinction. These two are technically and process-wise different businesses/business roles, but the same actor can decide to adopt both business roles. This type of business strategy increases the probability of customers buying both solutions from the same vendor. For an actor to expand to a new business role, it is easier when the new business role (e.g., corporate connectivity platform) is of a smaller total value than the actor's current business role (e.g., corporate data platform). Correspondingly, if the customer's value for these platforms has the same relative bias, the vendor's expansion becomes easier. Finally, the requirements for a local ecosystem such as the port to evolve from a fragmented data and connectivity configuration towards an optimally hybrid data and optimally centralized connectivity configuration include sufficiently advanced ICT technology to enable higher automation, as well as a sufficient level of competition (between ports, between similar stakeholders within a port) to incentivize innovation. This requires a sufficient level of trust between the port stakeholders, especially with the port operator.

5. Proposed management actions

Next, building on the alternative configurations presented in Chapter 4, we outline and define the required management actions for legitimately combing connectivity and data platforms within the platform ecosystem. Table 2 may be read as a state diagram that highlights the question of possible states and state transitions. This question of management actions will be discussed below using the case example and present a roadmap for a possible transition. Our proposed framework's feasibility can be tested by applying it in the practical case example by developing a strategic service roadmap for it. This roadmap starts from the typical fragmented configuration and results in an idealistic configuration, consisting of a centralized connectivity platform and a hybrid/centralized data platform. The optimally hybrid data platform with an optimally centralized connectivity platform discussed in the preceding chapter is considered legitimate here at the ecosystem level. However, individual ecosystem stakeholders may have different optimal positions. For the data platform, it is considered that a centralized platform would be the target, as the data platform providers could in such a position also offer connectivity bundled with the data platform. For the connectivity platform provider, the hybrid form could be considered optimal

Table 2
Connectivity and data platform configurations.

		Data platform configuration		
		Centralized	Hybrid	Fragmented
Connectivity platform configuration	**Centralized**	**Connectivity:** One dominant player for connectivity, either an MNO or a private network operator **Data:** One dominant player for data, cloud services or a local data intensive player **Services:** As-a-service mode	**Connectivity:** One dominant player for connectivity, either an MNO or a private network operator **Data:** Several data platforms with platform-specific data **Services:** Data-as-a-services	**Connectivity:** One dominant player for connectivity, either an MNO or a private network operator **Data:** Data in silos, no shared data One-to-one data sharing on demand **Services:** Self-service with data
	Hybrid	**Connectivity:** Several parallel connectivity providers, either MNOs, neutral hosts for connectivity (RAN multiple core networks) or private network operators **Data:** One dominant player for data, cloud service or local data intensive player **Services:** As-a-service mode	**Connectivity:** Several parallel connectivity providers, either MNOs, neutral hosts for connectivity (RAN multiple core networks) or private network operator **Data:** Several data platforms with platform-specific data **Services:** Data-as-a-service Connectivity and data services may be combined	**Connectivity:** Several parallel connectivity providers, either MNOs, neutral hosts for connectivity (RAN multiple core networks) or private network operators **Data:** Data in silos, no shared data One-to-one data sharing on demand **Services:** Self-service with data
	Fragmented	**Connectivity:** Everyone takes care of their own connectivity needs MNO provided or own connectivity **Data:** One dominant player for data, cloud service or any data intensive player **Services:** As-a-service mode	**Connectivity:** Everyone takes care of their own connectivity needs MNO provided or own connectivity **Data:** Several data platforms with platform-specific data Services: Data-as-a-service	**Connectivity:** Everyone takes care of their own connectivity needs MNO provided or own connectivity **Data:** Data in silos, no shared data One-to-one data sharing on demand **Services:** Self-service with data

as the connectivity providers have not typically provided all possible connectivity solutions in vertical industrial contexts. Connectivity platform providers have traditionally not provided data platform services for their clients either. However, this may change in the future. The platform users' optimal position could be to have an arms-length approach to both connectivity and data platform providers and have a hybrid form of both platforms if acquired as a service or centralized if the platform user itself manages them.

The proposed strategic digitalization steps for any multi-stakeholder industrial ecosystem can be listed as follows.

1. Fragmented data vs. fragmented connectivity
   a. Provide the stakeholders with solid human coordination (face-to-face, phone, email) and keep this capability as a fallback process when increasing the level of automation in the next steps.
   b. Provide the stakeholders with web-based manual access to initial centralized data services on the data platform (over fragmented private networks and through the Internet). This may include scheduling all arriving and departing cargo (vehicles, ships, trains) as an elementary service for situational awareness.
2. Fragmented data vs. hybrid connectivity
   a. Provide the stakeholders with a unified private connectivity platform (e.g., WLAN or 4G/5G) covering the whole area for accessing the centralized data platform. Some stakeholders may continue using their own fragmented private networks for their internal purposes.
   b. Provide the stakeholders with improved web-based situational awareness by adding IoT sensors to the unified private network. Examples include security surveillance (e.g., via automated drones and burglar alarms) and cargo follow-up (e.g., via uniform tagging and monitoring the containers' location).
3. Optimally hybrid data vs. optimally centralized connectivity
   a. Provide the stakeholders with automated interfaces between the stakeholder's internal and the centralized port data platforms. This further improves both the creation and sharing of situational awareness by enabling the stakeholders to share some of their specific database and IoT data. The centralized data platform replaces some functions in the stakeholder internal legacy data platforms.
   b. Enforce and incentivize all stakeholders to participate in the unified port network and port data platform's automated use.
   c. Continue optimizing the unified area connectivity (e.g., via slicing, edge computing) and data (e.g., federated data platforms, blockchain transactions) platforms for more demanding services.

As the above steps are based on a single case—and may well be case-specific—stakeholders in other ecosystems may well prioritize the order of strategic steps slightly differently due to the local history and context. Correspondingly, they may also prioritize the specific services differently. However, the proposed main evolution path, as visualized in Fig. 4, is typical and reflects the technical evolution in which the compatibility of connectivity platforms matures before that of the data platforms. This evolution order stems from the observation that the generic lower layers of protocol stacks evolve through standardization. In contrast, as more proprietary the development of the specialized upper layer application protocols may become standardized later on, de jure or de facto.

Regarding the optimal target configuration (green boxes in Fig. 4.), it is useful to consider the technical and platform ecosystem configurations separately. For different stakeholders, the optimal positions are different. For data platform providers (such as cloud service providers), the optimal position is to centralize the services, whereas connectivity platform providers (such as MNOs, or mobile network vendors) aim to become more hybrid in their offering. For any local player (such as facility users/owners or local operators) in the platform ecosystem, the optimal position would be to have both data and connectivity platforms hybrid. The developed target

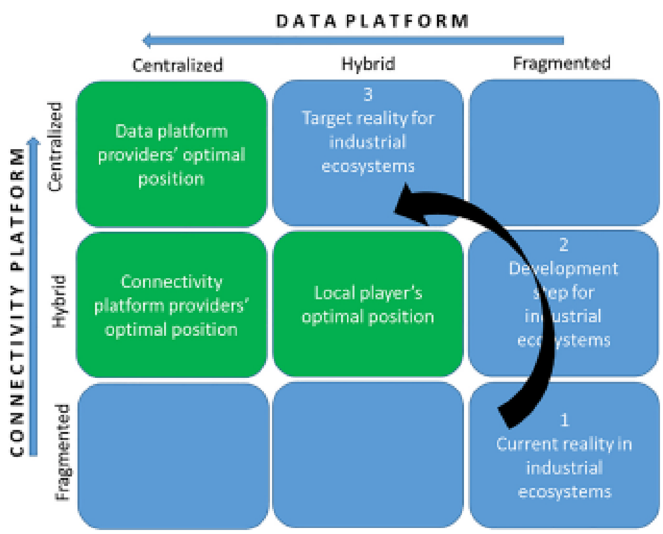

Fig. 4. Steps for converging connectivity and data platforms.

configurations for the data and connectivity platforms are presented at a rather high-level, without detailed technological solutions. However, due to technical advances such as virtualization and edge computing, the technical architecture s flexibility is improving. A critical aspect of the private and local 5G network in the multi-stakeholder ecosystem is the ability to create customized network slices, where instances of virtual network resources can be delivered to services tailored to specific stakeholder needs, with service-level agreed performance on demand. For instance, the late binding of the location of computation and data will enable application- and even session-specific allocation of resources along the client-edge-cloud route. This enables a single flexible data platform to stretch geographically and functionally to gain scale and scope benefits. This flexibility may also blur the traditional boundary between data and connectivity platforms. See, e.g., the 3GPP work on edge computing (3GPP TS 23.501) and the cloud networking features (Toosi & Buyya, 2017). Consequently, it will become possible that a single platform provider may gain a more dominant position over scale and scope, even across the data-connectivity boundary. Although from a local actor s, e.g., port operator s, viewpoint, it would be optimal to simplify things by minimizing the number of ecosystem platforms. This trend likely calls for regulatory attention.

6. Regulatory challenges influencing legitimacy of private and local 5G networks

The data and connectivity platform configurations for local and private 5G networks presented in Chapter 4 and the related management actions proposed in Chapter 5 are subject to the regulatory developments governing the use of the networks and their legitimacy in industrial multi-stakeholder ecosystems. Local private 5G networks deployment is a new mode of operations in the mobile communication market and subject to the national regulatory framework with some international aspects such as spectrum harmonization. These regulatory frameworks differ significantly from one country to another, while certain aspects can share a higher degree of commonality, such as among EU member countries through the EECC, creating a complicated operational environment for organizations.

Several regulation-related challenges were identified in the workshops and interviews of the case study on the port ecosystem with the potential to promote or slow down or even hinder the adoption of local and private 5G networks. This motivated us to look into more broadly what kind of regulatory challenges need to be addressed to allow widespread adoption of local and private 5G networks. The identified preliminary regulatory elements and examples of challenges are presented in Table 3. Availability of spectrum is critical for deploying the local networks, and national regulators have started developing local spectrum licensing models for mobile communication networks in some countries, leading to fragmentation between countries. The operator role defines whether the stakeholder operating the local 5G network is a telecommunication service provider like the MNOs with a set of rights and obligations. The emergence of new local 5G networks can potentially impact the market competition in a new way by both introducing more competition or by creating a local monopoly if the related regulations are not properly designed. Regulations on the access to infrastructure can leave the local 5G operator isolated if it is not a telecommunication service provider and other operators refuse to make commercial agreements with it. Radio equipment authorization on placing radio equipment on the market involves lengthy and costly authorization processes with national-level activities that vary between countries, limiting the availability and affordability of the networks and devices. The security and privacy elements are important in defining how the data and connectivity platforms can be used to collect and share various data. They have become increasingly important also in preserving national interests. Finally, when local and private 5G networks are introduced into specific verticals, the vertical-specific regulations play a key role in defining the rules of operating within the vertical, such as the port ecosystem in our case study, placing additional limitations which must be known and

Table 3
Identified regulatory elements and challenges for local private 5G networks in industrial multi-stakeholder ecosystems.

Regulatory element	Description	Examples of identified challenges
Spectrum	Spectrum management decisions aim to be effective by allocating spectrum to the right use, and to be efficient by assigning it to those who value it the most.	Long time spans in spectrum decision making. Limited availability of affordable spectrum locally. Incumbent spectrum hoarding.
Operator role	Case-by-case decision whether a local operator is a telecommunication service provider with respective rights and obligations, or not.	If the local operator is deemed to be a telecom service provider, it has to fulfill obligations. If not, others are not obliged to serve local operators, which can cause unfair market conditions or a local monopoly, and barriers to national roaming.
Competition	The goal is to maintain an appropriate level of competition in the markets, and to avoid the winner-takes-it-all syndrome of platforms.	Ensuring local competition in local/private networks. Slicing challenges in public vs. private networks. Vendor lock-in/captivity in local monopolies.
Access to infrastructure	Interconnection and interoperability legislation about the local network operators opportunity to use/connect to other stakeholders infrastructure.	Based on commercial terms for non-telecommunication service provider cases: operators can refuse to make contracts with private network operators and isolate them.
Radio equipment authorization	Rights to place radio equipment on the markets.	The current authorization process is designed for public networks. Country/region specificity involves complexity in getting approvals. Speed and cost of authorization process.
Security and privacy	Defines the rights and obligations on the collection and use of data (e.g., GDPR) and the use of networks and secures national interests.	Defining public/private areas. Rights and obligations concerning what can be done with local and private networks. Enforcing national policies.
Vertical specific regulations	Verticals are subject to their own legislation and regulations which can differ.	Regulatory complexities and controversies arising from verticals require domain-specific knowledge. Vertical-specific regulations are not designed for the latest ICT evolution.

taken into account already when planning the operations.

Regarding the regulation-related challenges seen from industrial multi-stakeholder ecosystems, the findings in Table 3 indicate the importance of several categories of items. The identified list cannot be considered exhaustive, and it can be assumed that the situation might be even more complicated in reality. The two major challenges observed for the widespread adoption of local and private 5G networks are the requirement to meet both the ICT and vertical-specific regulations in the given operational environment, which were not designed together, and the fragmentation of these regulations between different countries.

From the legitimacy perspective, the industry stakeholders passive legitimation strategy in regulative matters appears inefficient. Based on the findings, it appears no more sufficient to examine telecommunications or information technology regulations separately from the operational environment. To enable making private and local 5G networks legitimate, attention needs to be paid to connectivity and data platform combinations in different industrial contexts. The complexity and country-specificity of regulations may become a hurdle for the solutions scalability and replicability to international markets.

7. Conclusions

This research conducted a case study of a complex industrial multi-stakeholder, a 5G-enabled platform ecosystem of a port. In this kind of complex context, digitally enhanced situational awareness can bring value to several stakeholders in the ecosystem, thereby giving the impetus for building converged connectivity and data platforms and enhancing the vertically arranged ecosystem s transformation. Traditionally, data and connectivity platforms have evolved as separate technical and business entities. By analyzing the convergence of connectivity and data platform configurations in the port context, this research presents a configuration categorization of fragmented, centralized, and hybrid platforms and shows three steps of management actions illustrating how a legitimate platform ecosystem may develop. In this, a separation between data, connectivity, and services is needed as platform ecosystems typically need multiple data platforms and multiple connectivity platforms to perform well. Single platforms can, in practice, be isolated from each other (i.e., they may be fragmented), dominated by a single platform provider (i.e., be centralized), or be interconnected (i.e., be hybrid).

In the presented target configuration, a critical aspect of the private and local 5G network in the multi-stakeholder ecosystem is creating customized network slices, where instances of virtual network resources can be delivered to provide services tailored to specific stakeholder needs, with service-level agreed performance on demand. Furthermore, software-based network architecture enables cost-efficient infrastructure sharing by different tenants, opens the ecosystem to new players, and reduces service creation and activation times. The proliferation of increasingly powerful communication, computing, and analytics resources at the network s local edge provides optimized performance and economics for connectivity connected with performance-critical data services. The edge cloud provided by the connectivity provider or cloud service provider could enable platform convergence and become the control point for local connectivity, data, and services. A hybrid data platform model could improve coordination between stakeholders by sharing data in a centrally coordinated manner.

As each stakeholder typically has their own data platforms to serve their own internal needs, the convergence of data platforms and further digitalization may only take place in a legitimate way when and there is a common interest between the stakeholders. As a result, a federation of services and matchmaking types of activities may likely emerge in the platform ecosystem. The proposed optimally hybrid data platform with optimally centralized connectivity appears to be a legitimate configuration for converged connectivity and data platforms. This legitimacy is pragmatic by nature and at the level of the ecosystem rather than the whole industry. A multi-stakeholder ecosystem going through digitalization requires a clear central player to orchestrate the development. This role naturally belongs to the platform s central actor, who needs to make several make-or-buy decisions regarding its services. As the port example showed, virtually all stakeholders play a role as providers of data for situational awareness and could use it to enhance their operations. Converged connectivity and data platforms and related complementary services can be offered in the future by different players. Cloud providers might also offer connectivity as a service as dealers, and connectivity providers could use their edge cloud to offer data services.

This research has also identified a set of regulatory challenges related to the deployment of local and private 5G networks in complex, industrial, multi-stakeholder ecosystems where the telecommunications- and information technology-related regulations meet with vertical-specific regulations, leading to a complex operational environment. Moreover, as the regulations appear highly country-specific, with large differences between countries, this may slow down or even prevent this promising market opening to local private vertical-specific network deployments. In conclusion, to achieve industry-level legitimacy and scalability of the solutions, a widespread approval of the regulative bodies is needed for local and private 5G network deployments.

Although this research is based on a single, futures-oriented case study, the findings presented in this research suggest future research to focus on the creation of more detailed techno-economic value configurations of converged connectivity and data platform ecosystems and to study the role of edge cloud and cloud service providers in the different kinds of platform ecosystems. Finally, complex industrial multi-stakeholder ecosystems provide an exciting research context to study regulatory starting points and consequences in the intersection of telecommunications, information technology, and vertical-specific regulations.

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